Direct Observation of Defect structures in Ga-polar and N-polar GaN Epilayers by Cross-sectional Cathodeluminescence

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Difference in the defect-formation and/or growth-mechanism between Ga-polar and N-polar GaN epitaxial layers has been studied by using the cross-sectional cathodeluminescence (CL) characterization at both 80 K and room temperature. The CL system was attached in the field emission scanning electron microscope (FE-SEM), and very low accelerating voltage such as 2~3kV was used so that high-resolution cross sectional CL images were obtained due to the small penetration depth (30~60nm) of low energy e-beam.

The epilayers were grown on sapphire substrates by MOVPE and monitored with in-situ ellipsometry. The polarities of these epilayers were controlled by the sapphire nitridation and the trimethyl-aluminum(TMAl) pre-flow just before the conventional two-step growth, and were confirmed with CAICISS. Distinct cross-sectional CL images of GaN epilayers with Ga-polar and N-polar, which demonstrate different defect structures, were analyzed systematically, and explained in the highlight of different growth mechanisms of the epilayers with different polarities by the combination of the ellipsometry and XRD results.

For the Ga-polar GaN epilayers, isolated pyramid-like dark regions close to the film-substrate interface and clear column structure in the upper layer are observed in the cross-sectional CL images. Fig.1(b) shows the panchromatic CL image which was taken with an e-beam energy of 3keV . The cross section is very smooth as shown in fig. 1(a), which is a SEM image taken at the identical region to fig. 1(b). Thus, the influence of morphology on the CL image can be neglected. The isolated pyramid-like dark regions shown in fig.1(b) form a layer with a thickness of about 700nm just above the interface. These dark regions correspond to the isolated islands which were formed during three-dimensional(3-D) growth stage. These islands include very high density of defects resulting in very weak CL. In the upper layer, however, many dark lines along c-direction of the epilayer form columns. These dark lines are originated from the threading dislocations(TDs), nanopipes and grain boundaries as well. This is confirmed by our quite fine surface CL images which show that TD arrays are present in small angle grain boundaries in order to compensate their misorientation.

Furthermore, the cross-sectional CL images show that the 3-D growth layer plays a crucial role in defect reduction in Ga-polar GaN epilayer. Fig.1(d) shows a very thin 3-D growth layer, and high density of dark lines in upper layer as well. XRD measurements performed on this sample show bad structural quality. For this sample, small islands formed during the 3-D growth stage resulting in the small size of the grains in upper layer, thus, the defect density is high. For the sample with thick 3-D growth layer, on the other hand, pyramids were well developed, and, big grains were formed in upper layer consequently, and the defect density was reduced greatly.

As for the GaN epilayers with N-polar, their cross-sectional CL images show quite different defect structure from those with Ga-polar. Fig. 2(b) shows cross-sectional CL image at 365nm. Small dark and bright regions are observed in this CL image instead of column structure. The bright regions are irregular, and their average size depends on the density of dark regions which are related with the defects lying in the epilayer. These defects act as the non-radiative centers, causing weak CL in these local regions. Due to the strong bond in N-polar GaN, the N and Ga atoms have very short migration length when they reach the lattice sites. So, the surface of the N-polar GaN film always includes hexagonal hillocks. During the growth process, no transition occurs from 3-D to quasi 2-D growth mode for N-polar samples.

In Summary, quite different defect structures in Ga-polar and N-polar GaN epilayers were revealed by using the highly spatially resolved cross sectional CL images. And, the difference of defect formations was explained by the different growth mechanisms in Ga-polar and N-polar GaN epilayers.

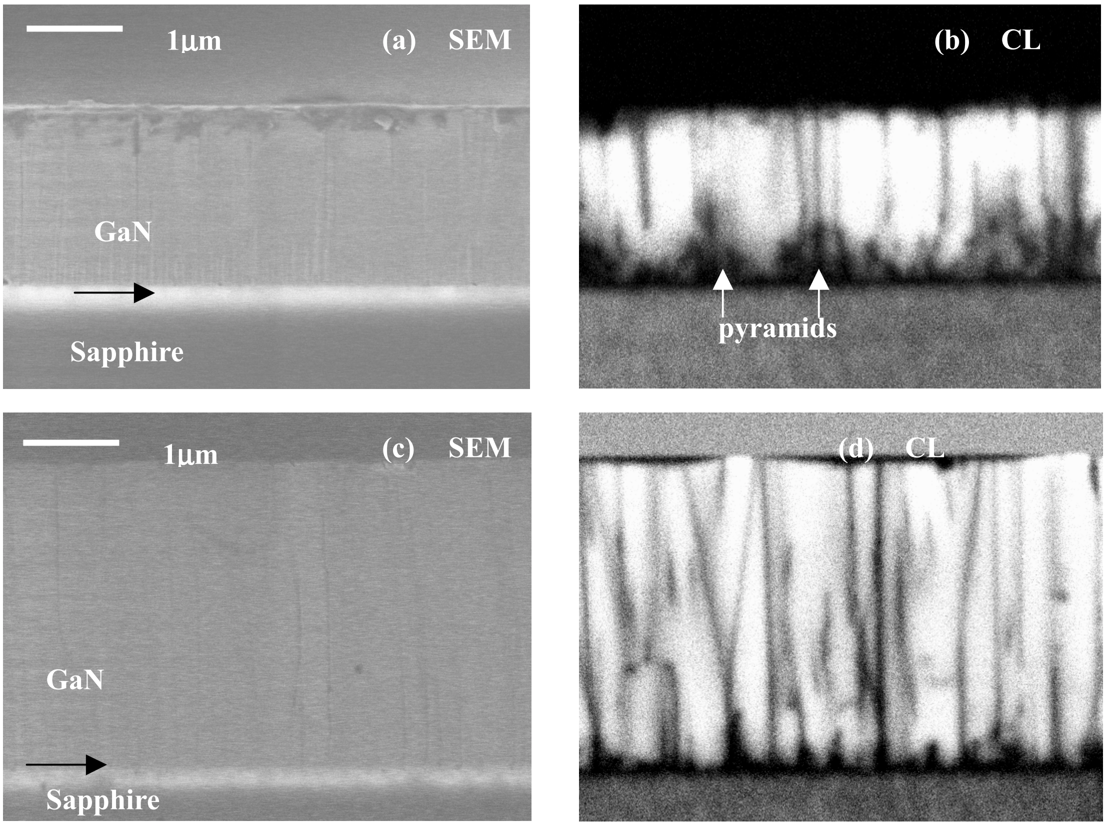

Figure1, Cross-sectional images of Ga-polar GaN samples with different defect density; (a), (c) SEM image; (b), (d) panchromatic CL images of the identical regions to (a), (c) respectively

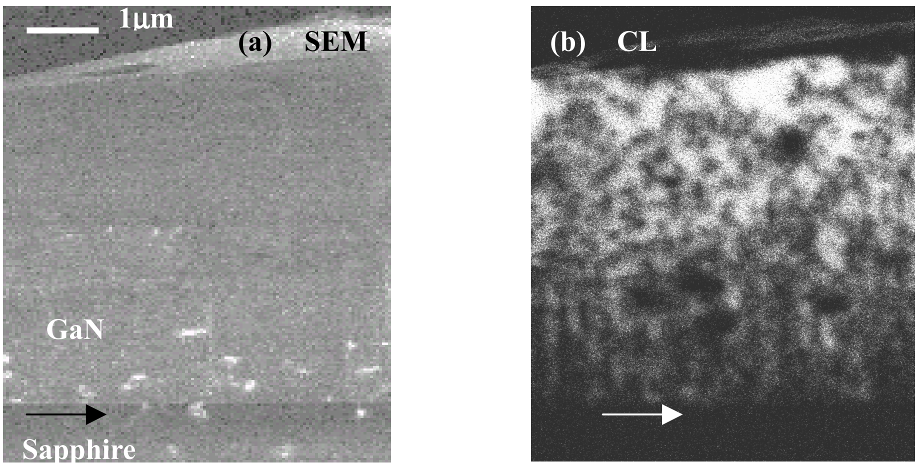

Figure2, Cross-sectional images of N-polar GaN sample; (a) SEM, and (b) CL at 365nm of the identical region